Lessons Learned:
SRF Testing and Activated Components

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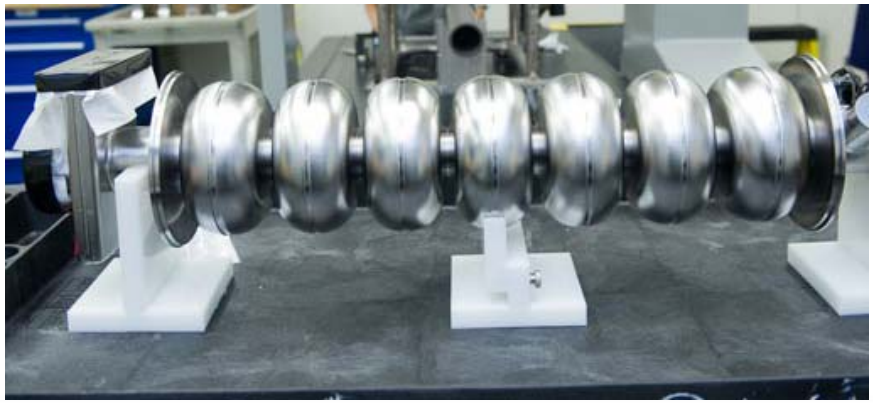
SRF Testing and Activated Components

- SRF Technology
- Radiation Source Term
- Recent JLab Experience
- Take-home Lesson

SRF Technology

- Superconducting Radio Frequency Technology
  - Niobium-based superconducting resonant cavities excited by RF
    - EM field accelerates and imparts energy to the charge particles when they are in phase with the electric field
  - Absence of resistive heating allows near CW vs. pulsed beam conditions
    - copper at 300K & 1.5GHz, $R_{s\ Copper} \sim 10 m\Omega$
    - For bulk Nb at 2K $R_{BCS} \sim 10\ n\Omega$
  - Refrigeration at 2K requires about 10 KW of power: two orders of magnitude less power than copper cavities operating at room temperature in pulsed mode



SRF Technology, cont'd.

- Technology in use at major accelerator facilities
  - ORNL: Spallation Neutron Source
  - Fermilab: Project X
  - Facility for Rare Isotope Beams
  - DESY: XFEL
  - Energy-recovering linear accelerators driving fourth-generation light sources, e.g. Jefferson Lab's free-electron laser
  - Compact accelerators for university laboratories, accelerator-driven systems for nuclear power production in India
- Research is national; and global
  - Labs in the US: FNAL, BNL, ANL, JLab
  - Michigan State, Cornell Universities
  - Europe, China, India
- Will be used for International Linear Collider at CERN

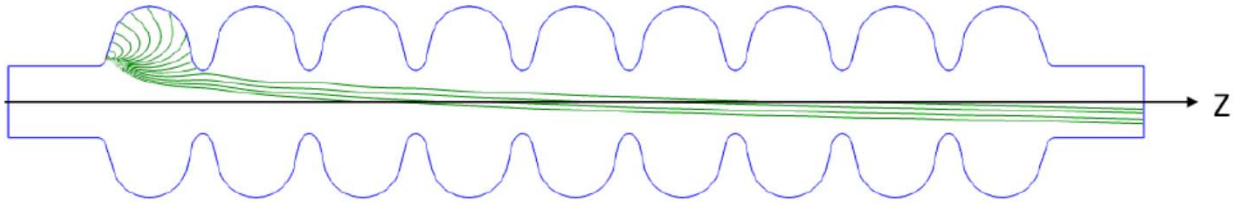
SRF Technology, cont'd.

- Two fundamental limits for a SRF cavity:
  - A critical RF magnetic field above which the perfect superconducting state is destroyed
  - The surface resistance as predicted by the microscopic BCS theory
- Research aimed at improving conditions that limit accelerating gradient
  - Developing material science, surface preparation and cleanliness techniques
  - Field emission
    - limits gradient when local heating due to field-emission causes superconducting conditions to degrade and cavity performance to reduce
- Limits of SRF Technology not reached: research on-going
  - Max achievable gradient thought to be ~ 50 MV/m
  - Current technology can reliably develop ~ 38 MV/m

Radiation Source Term

- R&D: material properties, then cavity performance, then cavity string performance under beam conditions
- Recent publications provide good description of / modeling of field-emitted electron coupled to RF and transported (accelerated) in a cavity
  - The resulting X-rays and, depending on gradient, neutrons are important data

Fermilab-Conf-10-246-APC-TC "Shielding studies for superconducting RF cavities at Fermilab," C Ginsburg and I. Rakhno.



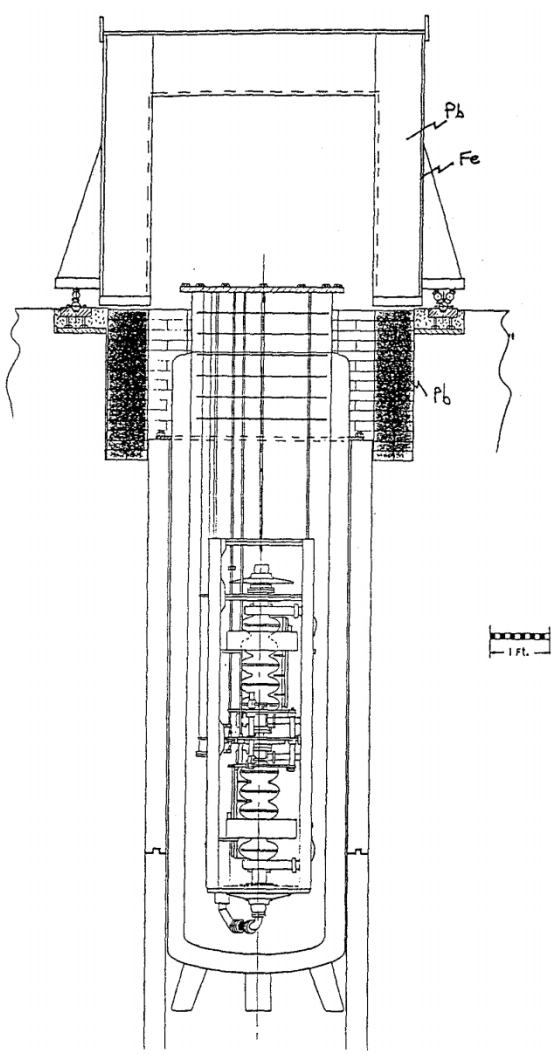
See also

Optimization Studies for Shielding of a Superconducting RF Test Facility, C. Ginsburg and I. Rakhno, Proceedings of IPAC'10, Kyoto, Japan WEPEC056

Radiation produced by the LEP superconducting RF cavities, M. Sileri, et. al., Nuclear Instruments and Methods in Physics Research A 432 (1999) 1}13

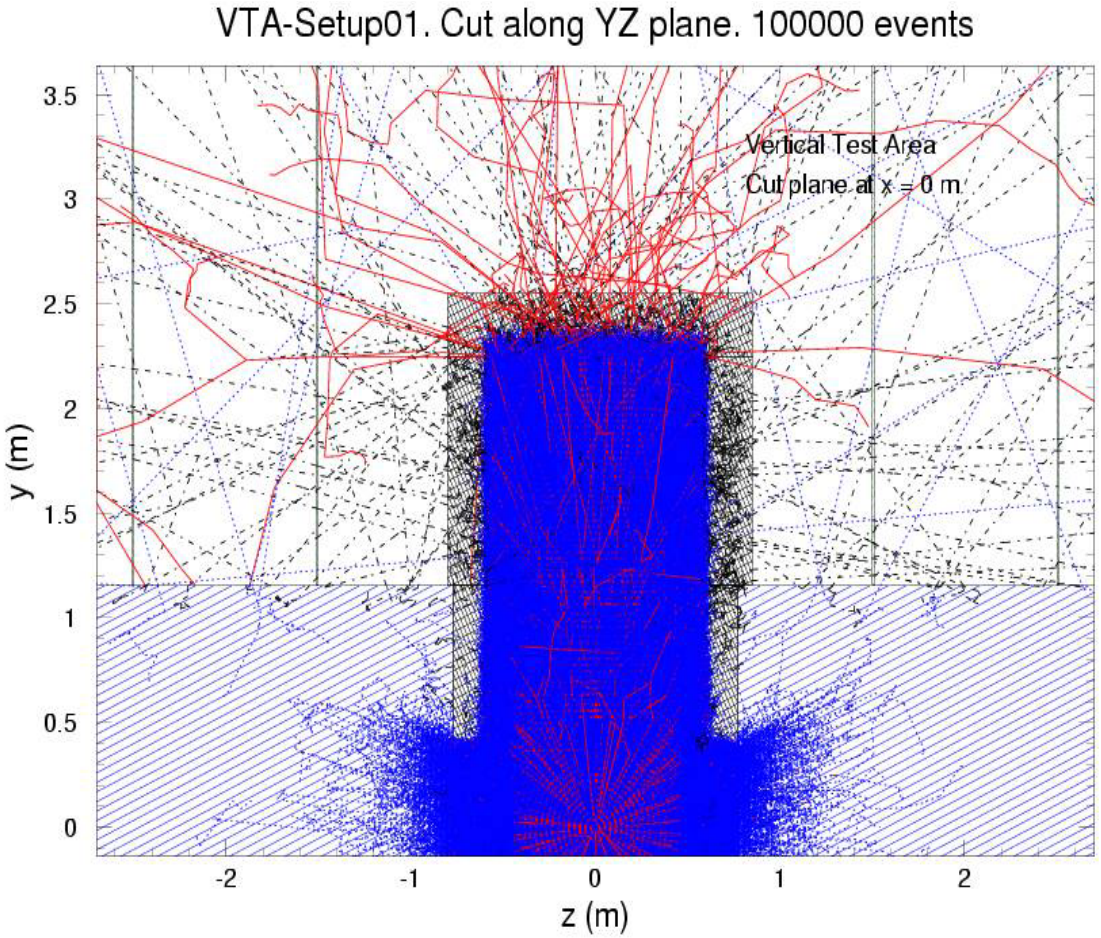
SRF Vertical Test Area at JLab

SRF Vertical Test Area at Jlab, cont'd.



- Original VTA shielding design did not include neutrons in the source term; no neutron shielding
- As gradients increased, neutron surveys conducted on "hottest" cavities – no significant production
- Area monitoring system upgraded in 2003 (added area neutron monitoring) with gradients in double digits
- No routine neutron-production – one cavity in 2008 (42 MV/m)
- Began spot-checks for activation
- July 2011, first activated cavity

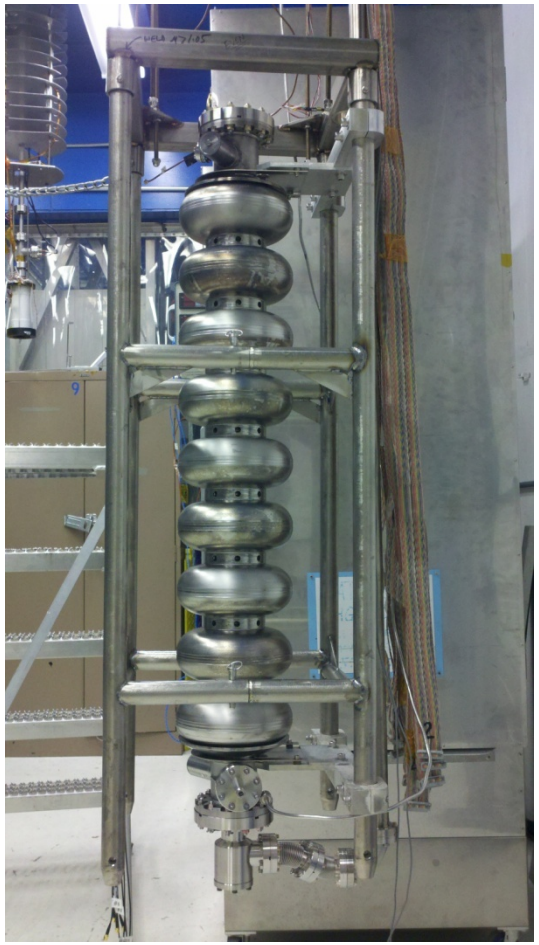
Radiation Source Term, cont'd.



Geant Model

- Postulated worse-case scenario
- 40W, 40MeV electrons
- 3-5 krad/h inside
- Maximum dose rate next to shielding: 10-15 rem/h
- 5-8 rem/h at 1-2 ft from the shield
- Blue –photon
- Red – electron
- Black – neutron
- Dose outside is about equal proportion photon/electron/neutron

SRF Cavity, Shielded Dewar

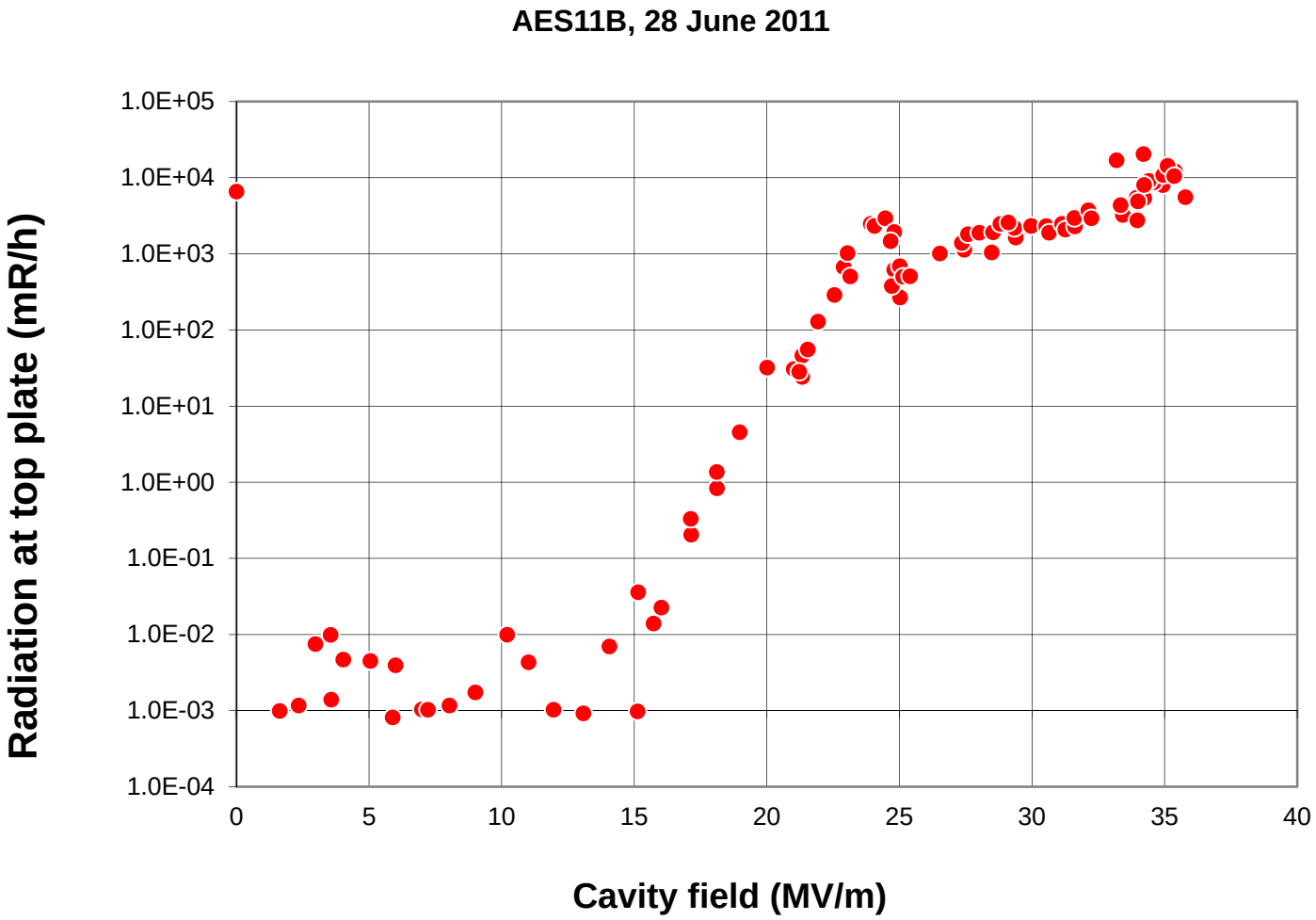


Radiation survey inside vertical shielded dewar in Vertical Test Area

9 cell cavity in test fixture

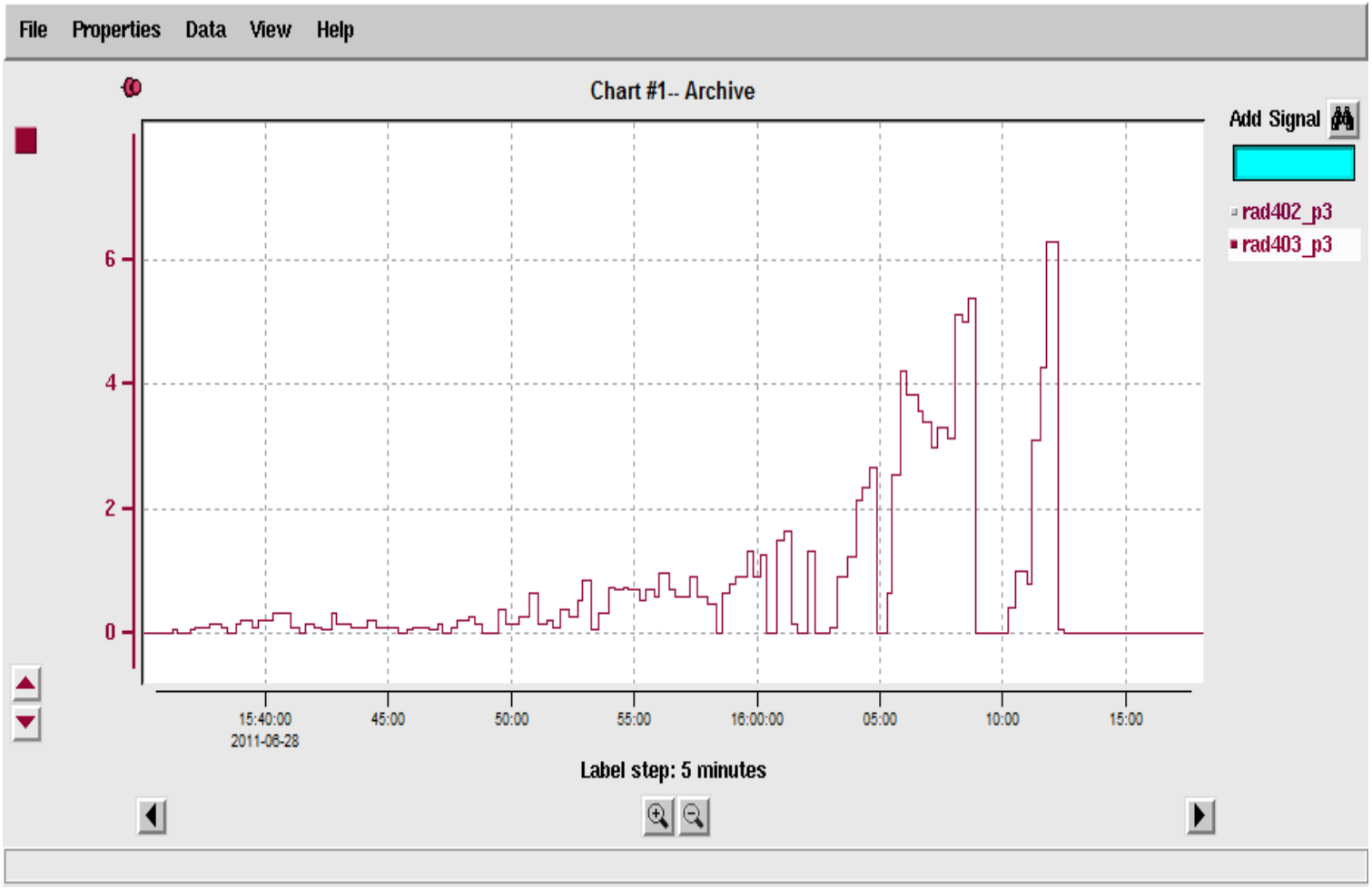
Recent JLab Experience

- Cavity AES11 – gamma exposure rate inside shield ~ 3 m from cavity



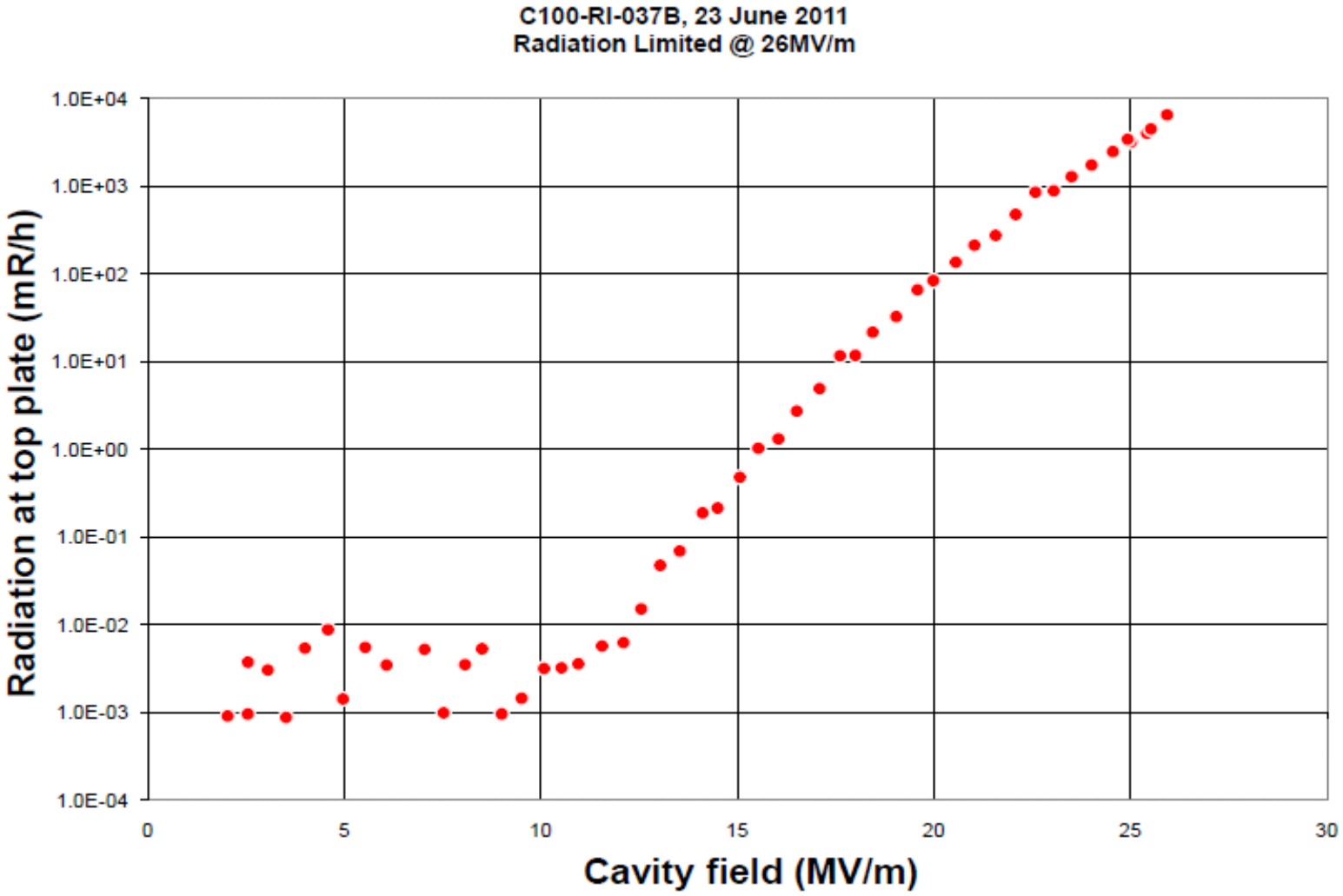
Recent JLab Experience, cont'd.

- AES11 Area neutron monitoring results several meters from shielded cavity



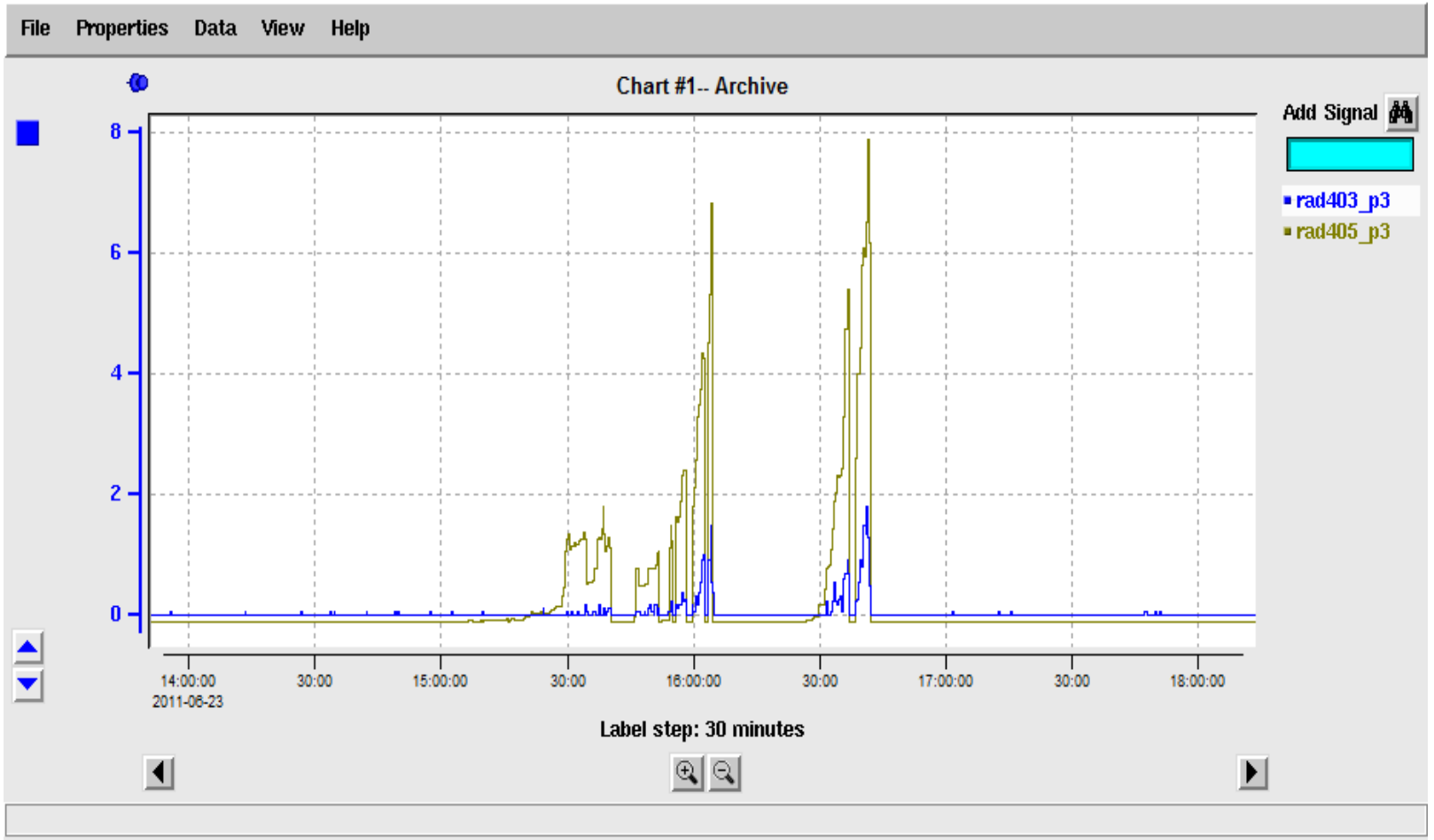
Recent JLab Experience, cont'd.

- Cavity C100-RI-37 gamma exposure rate inside shield ~ 3 m from cavity



Recent JLab Experience, cont'd.

- C100-RI-37 Area neutron monitoring results several meters from shielded cavity

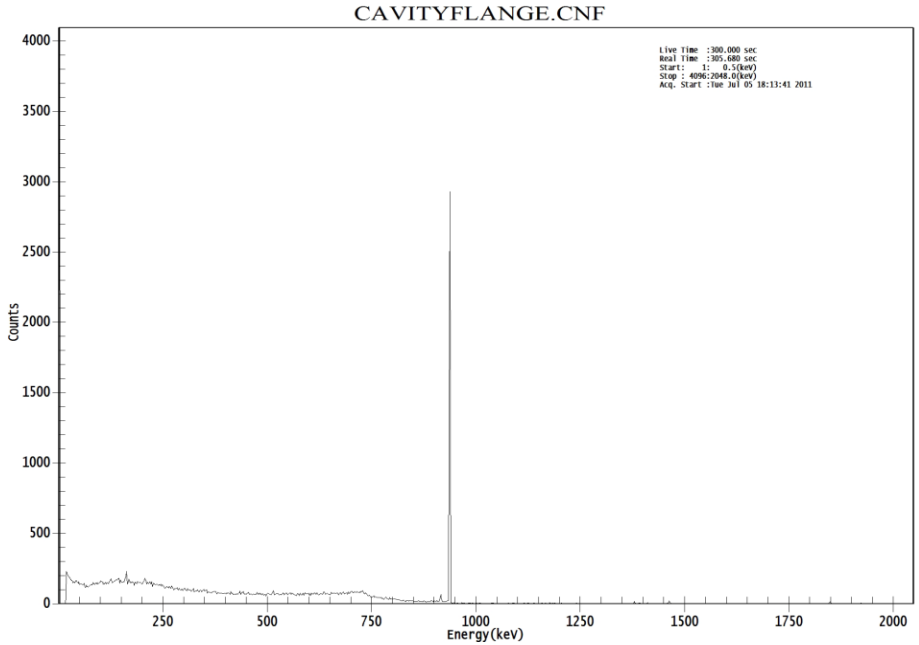


Recent JLab Experience, cont'd.

- Until recently, neutron production did not translate into activated components
  - Nominal condition for activation: a series of cavities properly phased and transporting an electron beam
  - Recent improvements in cavity performance prove a single cavity under test conditions is capable of developing detectable activation
- It is evident that all cavities that make neutrons do not become activated:
  - C100 cavity (7 cell) showed no activation and AES11 (9 cell) showed activation on "bottom" flange (~ 2 mR/h on contact)
  - Most cavities do not produce high photon levels or neutrons:
    - AES06 was tested on 7/1 and 7/5 making 36 MV/m with little radiation (~100 mR/h gamma)
    - "DESY Seamless" tested on 7/7 making ~1 R/h gamma, no neutron
- Function of geometry, gradient, and field emission

Recent JLab Experience, cont'd.

- In-field gamma ray spectrum of activation



X-ray energy in excess of (γ,n) thresholds

Nb-93(γ,n)Nb-92m
E_{Thresh} ~ 9 MeV

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
Nb-92m	0.888	934.50*	95.50	1.63608E+000	7.36494E-002

- Nb-92m only significant nuclide in Nb cavity
- Ni-57, Cr-51, others seen in attached hardware (mostly SS)

Current Status/Lessons Learned

- Current practice at Jlab
  - All multicell cavities receive survey
  - Compiling process knowledge for development of survey thresholds
  - Investigating advanced source term analysis
- EH&S Program must be
  - Tightly coupled to SRF R&D activities
    - Shared data is key to anticipating changes in source term
  - Conservative in approach
  - Flexible enough to respond with incremental controls
    - Provide required safety measures
    - Tailored to allow continued R&D